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BOOK REVIEW

QED : The Jewel of Physics
(Quantum Revolution II)
133 pages, illustrated, price Rs 65 00 (soft cover),
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What is Reality?
(Quantum Revolution III)
128 pages, illustrated, price · Rs 65 00 (soft cover);
ISBN 81-7371-004-x
by G Venkataraman
Universities Press . Hyderabad, India (1997)

In the last few years, the series of small books by Dr. Venkataraman, aimed at a general, but scientifically literate, alert and curious audience, have successfully communicated the excitement of physics to students and professional researchers alike. As mentioned in the preface, he has chosen Richard Feynman as his model of an ideal communicator. Indeed, the author would like these books to be referred to as some kind of a junior version of the Feynman series. Scientists and science students all over the world, are familiar with the mix of superb clarity, humour and brilliant insights which characterize the writings of Feynman. The author has consciously set a very high standard, and has striven hard to achieve that standard, and in this process, has been able to make wonderful expositions of some current frontline areas of different branches of physics.

The present two books are the second and third volumes of his trilogy, "The Quantum Revolution" (We are presently not concerned with the first volume, "The Breakthrough"). Of these two volumes, the first one, entitled QED, tells the story of perhaps the greatest triumph of the human intellect in the twentieth century. The final volume of the trilogy deals with the quantum mechanical view of reality, a topic on which there is no clear consensus.

Inevitably, Richard Feynman is the chief protagonist of the story told in QED, because it was he who brought quantum electrodynamical computation to the masses, in the words of Julian Schwinger. The author starts with a brief report of the status of QED in pre-war years and the problem of infinite self energy of a charge in classical and quantum electrodynamics. Feynman's radical approach to the space-time trajectory of electrons has been introduced in the context of Dirac's theory of the electron.

The second chapter takes us straight to the Feynman approach to QED. His path integral approach in principle, embraces all of classical optics and mechanics starting from the same set of equations. The author explains how the famous Feynman diagrams are used to keep track of the interactions. Drawing these diagrams is comparatively easy, but we must remember that they do incorporate all the complex mathematics of interactions at the junctions, precisely determined by the rules of QED. As demonstrated by examples of different physical processes, it is possible to visualize from the relevant diagrams exactly what is going on even without going through the mathematics. The number of junctions in a diagram depends on the order of the perturbation. They are Lorentz invariant and the infinities arising from self energies at the junctions are always of the kind that can be removed by renormalization. Renormalization, though it works wonderfully, is a tricky and not quite satisfactory concept, which Feynman himself described as a way of hiding the difficulties with the theory under the carpet. The author succeeds in the difficult task of explaining all these ideas in everyday language without avoiding the conceptual difficulties. He points out the mathematical soundness of the renormalization procedure and remains careful enough not to oversimplify the physical picture. In fact, he stresses the difficult points.

Of all physical theories, QED perhaps gives the most precise agreement with experiment, (for example, the discrepancy between the measured and calculated magnetic moment of the electron comes out to be .00000002%). No account of this theory can be complete without a discussion of the major experiments in this field and the explanations of the results in terms of the most significant diagrams. The third chapter contains descriptions and explanations of three such experiments : the Lamb Shift in Hydrogen, the anomalous magnetic moment of the electron and the splitting of the ground state of the Positronium.

Finally, the path integral approach to QED is distinguished from the relativistically invariant differential approach of Schwinger and Tomonaga. The same results are obtained from both approaches, once the business of renormalization is properly performed. The author stresses that relativistic invariance of every stage in the mathematical calculations must be carefully ensured. He however, sums up the difference between the two views of QED as a difference between two world outlooks : "The Hamiltonian method represents the future as evolving from the past *via* a differential equation but Feynman was not satisfied with that because he wanted to take in both the past and future in one grand sweep". Though for explaining the observed facts one theory is as good as the other, the path integral method can lead to new insights into other physical theories, such as QCD, describing the strong interaction between hadrons. The author quotes Gellman as saying that the path integral formulation is applicable to quantum cosmology where other methods fail, and in this sense, this method must be more fundamental. This point has been treated in the final chapter. Before these discussions, the issues of infinities and renormalizability of the wave function are raised again. A sample of opinions from the main characters of the story regarding the unsatisfactory nature of the renormalization procedure is given. The author also manages to give a nice round up of the path integral approach, relating the different physical variables appearing in different formulations of the theory, and pointing out their connection with the perturbation theory.

Finally, brief sketches of the personalities of the principal actors in the drama, namely, Tomonaga, Schwinger and Feynman are given. Given the rich variety of biographical material on Feynman available, it is he who comes out most alive in these pages, though some of the anecdotes must be well known to any person who has continued this far. In the penultimate chapter the author gives a historical account of the development of QED in its modern form after the second world war. Of course, a lot of material is available, but they are rather technical. The author has done a wonderful job of weaving the various threads of the story into a pleasant and readily comprehensible pattern. Mainly with quotes from reminiscences, the author succeeds in making this chapter quite an interesting, and at times, absorbing account. On the whole, this book should be able to acquaint the curious reader with the fundamental issues of QED.

In spite of its breathtaking success in explaining natural phenomena, there are deeply disturbing aspects in the basic foundations of quantum mechanics. Of course, almost all working scientists feel quite content in applying the quantum mechanical tools in their everyday work, and in case any doubt ever arises, there is always the Copenhagen Interpretation (CI) to fall back upon. It really does not matter that on deeper inspection the objective reality of the material world seems to dissolve away under the CI. In the small book "The nature of reality", the author has managed to give a reasonable and accurate picture of these troubles and the various attempts to solve them. The current status of the foundational aspects is clearly assessed in a non-technical language. This book will be useful to a wide range of readers with very different levels of expertise and specialization.

The founding fathers of Quantum mechanics were fully aware of these troubles and their implications but they did not feel too uncomfortable with it. The author quotes Niels Bohr : "There is no quantum world. There is only an abstract quantum mechanical description". Schrödinger was however not happy, and Einstein remained dissatisfied with the implications of the concept of quantum measurement He tried to lead a sort of revolt against this so called Copenhagen view. Einstein objected to a theory in which values can be attributed to physical parameters only when they are measured. To some extent such opposition was philosophical, but the scientific bottom point was that if some correlation allowed us in principle to have knowledge about conjugate variables which is forbidden by the Uncertainty Principle, then quantum mechanical description of physical reality cannot be considered complete. Einstein proposed such a thought experiment in the famous EPR paper. Bohr rejected this notion of incompleteness as unnecessary philosophical baggage and found it more convenient to maintain that physically real attributes of a particle only materialize when we look for them. The author makes fun of his style, and the quotations from Bohr given in this book certainly justify the author's contention. However, the hypothetical EPR experiment concerned itself with correlations between particles over a macroscopic distance and in this context Bohr could prove his point only by incorporating the classical measuring apparatus as part of the quantum system. This blurring of the distinction between a classical measuring apparatus and a quantum system, so essential for CI (though we must admit that the distinction was never absolute to start with) led to all sorts of troubles.

The troubles were brought into the forefront in a most dramatic fashion by the hypothetical cat of Schrödinger. A well known thought experiment with the cat raised this particular issue of defining a boundary between a macroscopic classical measuring apparatus for finding the state of a quantum system, and the system itself. According to standard quantum mechanics, any object, including a cat, can be described by a wave function which itself collapses as it is observed. Now, both the cat and the observer are macroscopic objects and nothing prevents us from including the wavefunction of the observer in the description of the system. This leads to the problem, which in philosophical parlance is called infinite regress. The author scrupulously presents all possible counter arguments, which can be legitimately raised by the Copenhagenists. The crux of the problem however, is that there is no prescription in quantum mechanics for wave function collapse on interaction with a macroscopic apparatus. In fact, there is no consensus on what kind of interaction should cause that collapse. This problem raises its head in a most dramatic form in quantum cosmology where, by definition, there cannot be an outside observer causing the collapse of the wavefunction of the universe.

In the meantime, it was realized that if Einstein is right about the incompleteness of quantum mechanical description of reality, then there should be some hidden variables which, together with the usual quantum mechanical ones, could be used for a deterministic description of the universe. Though the problem has not yet been resolved in its full generality, it has been established beyond doubt that quantum theory is complete for microsystems in the sense that introduction of hidden variables in a theory respecting local causality (local reality theory) would not lead to a deterministic theory. Experiments similar to EPR have been designed in which a local reality theory with hidden variables would give measurable outcomes different from the standard quantum mechanical theory. In this context the author discusses the famous Bohm-Aharonov proposal of the measurement of spin components of correlated electrons and the less well known Mermin's thought experiment. All these have been put within a comprehensible theoretical framework by the work of John Bell. This mathematics was a great step forward in establishing the validity of quantum mechanics or alternative local reality theories, through results of real life experiments requiring rather special conditions.

All such actually performed experiments violate the Bell inequality, confirming the correctness of the traditional quantum viewpoint, which insists that there is no deeper reality hidden in a still unexplored level beyond that described by the wave functions. The most convincing experiment was performed by Alain Aspect, in which the correlation between far away photons is measured in rapidly changing conditions with the changes occurring before a signal can travel from one part of the apparatus to the other. Aspect's experiment is the fundamental delayed choice experiment, which, because of its importance, has been treated in some detail in this book. Thus local causality need not apply to quantum correlations and the wave function of the universe can get inextricably entangled, in principle.

In another interesting chapter, the author discusses a proposal from India made by Partha Ghosh, Dipankar Home and G S Agarwal (GHA). Based on an experiment, conducted way back in 1897, by J C Bose, they predicted that the formalism of quantum mechanics should allow the simultaneous observation of both particle and wave aspects of a single photon, contradicting the principle of complementarity. This experiment has actually been performed, confirming the GHA prediction and raising doubts about at least one important aspect of Niels Bohr's way of looking at the world. The author emphasizes that the debate on this is likely to go on for some time.

Again, the results of Aspect's experiment are bound to raise questions of a different category. In short, it will be "What if such experiments are done with cats instead of photons" ? There is a chapter devoted to the principle of such an experiment titled "Laboratory cousins of Schrödinger cats." Again, whatever we know about the wave function (of cats or anything else), we do with the help of our consciousness. So do we need to bring consciousness into the picture ? There are serious ongoing controversies on this particular issue, perhaps with a bearing on the nature of life itself. Speculations of various kinds are made everyday. We are duly warned however, that this is a game for "adults" and not "kids".

The final chapter gives us a grand overview starting from the inception of the debate about the nature of quantum mechanics in the 1930's. The different way-outs suggested, are presented through a chart which broadly divides the opinions into those which do or do not maintain that a major change in the machinery of our interpretation is essential. The author summarizes the arguments of both sides starting with those of the diehard Copenhagenists who want to preserve intact the elaborate interpretive structure of the Copenhagen school and in one sense may be termed as conservatives of today. He also mentions the participatory universe view of Wheeler, which insists that the observer participates in creating the reality. In Wheeler's words, "the past has no existence except as it is recorded in the present." Though this type of discourse can be extremely confusing, the concrete examples of delayed choice experiments have been able to some extent to illustrate this viewpoint. The most interesting point is the argument that the whole universe can be thought of as a result of a delayed choice experiment, and thus is a participatory universe. This leads to an attempt to relate Wheeler's viewpoint to the well-known Anthropic Principle.

All these may be interesting philosophical points to ponder on, but it is not clear where we stand on the problem of quantum measurement itself. Somewhat more familiar and more to the point is the many universes hypothesis of Hugh Everett, which many scientists consider to be the most graceful way out of the dilemma of quantum measurement and consequent wavefunction collapse. Its great merit is that it leaves the whole structure yielding practical results totally intact. The author insists, that this hypothesis is a serious alternative from a mathematical point of view, though from a philosophical standpoint it is disturbing because it is "expensive on universes." Physicists like Bell or Peierls have put violent objections to this way of resolving the issues. Another alternative to the standard interpretation presented in the book is the Bohm-Hiley non-local theory.

The author concludes the book with a short transcription of a conversation between Einstein and Tagore. Einstein firmly maintains that there always exists a reality independent of man and a truth relative to that reality, while Tagore argues that in some instances at least, the only tangible reality is that created by the consciousness of man. In Tagore's view the so called truth of Einstein unrelated to human consciousness will remain illusory as long as we continue to be human beings. These arguments of the early 30's foreshadow the present debate about the nature of reality in a remarkable way and the author has done an excellent job to end on the note.

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